32.3 Advanced MMIC for Passive Millimeter and Submillimeter Wave Imaging

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Passive detection of millimeter wave (PMMW) radiation for imaging holds great promise as a means to see concealed weapons and to aid aviation in low visibility conditions [1]. This requires compact cameras sensitive to the pW radiation typical of most scenes. Our passive millimeter wave (PMMW) cameras are based on 2D planar arrays of total power radiometers serving as the imaging focal plane array (FPA). The overall architecture includes a set of imaging lenses that focuses the incoming MMW radiation onto the FPA. Each receiver includes an LNA followed by a rectifying diode to convert the received signal into a video rate voltage whose amplitude is proportional to the power received by the element (Fig. 32.3.1). The final image is generated by assigning a gray scale to the voltage and plotting the 2-D array of data. Image quality depends strongly on receiver sensitivity, of which noise figure, bandwidth, and video rate integration time are critical parameters. Figure 32.3.2 shows two 94GHz images. The imaging of the camera is diffraction limited (the angular resolution achievable by the camera is inversely proportional to the product of the aperture diameter and the frequency of the radiation being imaged). Thus, to maintain the angular resolution while using a smaller lens, the operating frequency must be increased.

Reported here are amplifiers, using 70nm and 35nm InP HEMT transistors, for PMMW imaging made possible by these technologies. Using state-of-the-art III-V HEMT MMIC technologies with increasing speed [2,4,7], a series of LNAs have been developed at frequencies ranging from 90GHz to 200GHz for the PMMW camera [3,5,6,8], as detailed in Fig. 32.3.3.

More recently, a cascode LNA has been designed using our 70nm InP HEMT MMIC process (Fig. 32.3.4). The cascode topology demonstrates higher gain compared to a common source, which is advantageous for high frequency applications where available gain is limited [9]. Additionally, conductor losses increase with frequency, while device gain is harder to achieve. Generally, cascode stages do not demonstrate as low noise figure as common-source stages, so an optimum amplifier topology is to cascade the first stages as low noise common source stages followed by high gain/stage cascode stages to achieve the best overall performance for these high frequency LNAs.

The cascode design uses two-finger devices with a periphery of 30µm. A low-impedance transmission line at the gate of the common-source device provides a modest amount of matching. This single-stage cascode design is used for capability evaluation and model extraction. A shunt stub with an *RC* network at the drain provides stabilization at the output. Measured performance of the circuit is shown in Fig. 32.3.5. The drops in gain at 170GHz and 200GHz are attributed to “suck-outs” occurring from coupling to adjacent structures in the on-wafer measurement. However, the measured circuit performance illustrates the benefit (a higher gain per stage) of the cascode design at high frequencies. For example, 8dB gain from 145 to 165GHz was achieved where typical common source single stage circuits would exhibit about 4 to 5dB at this frequency range.

To further explore the limits of LNA technology, the most recent InP HEMT development has reduced the gate length to 35nm. This technology has recently measured transconductance of 1600mS/mm with good breakdown voltage of 2.5V, f_T of 400GHz, and f_{max} > 600GHz. On-wafer measured results for a single stage CPW common-source amplifier using two-finger devices with a periphery of 30µm is shown in Fig. 32.3.6 and demonstrated a measured gain of 4dB peaked at 260GHz, not including the loss of the launch with 1.25dB gain up to 300GHz. Also designed and measured were CPW common-gate single-stage amplifiers, which demonstrated ~4dB gain at 310GHz (Fig. 32.3.7), the highest gain measured at that frequency to date. No attempt has been made to de-embed the losses of the launch, which are appreciable at these frequencies (as much as 1 to 2dB). Additionally, this circuit does have thin-film resistors, which reduce gain to enhance stability as common-gate amplifiers are typically difficult to stabilize at high frequencies due to series inductance between the device gate and ground. This is, to our knowledge, the first gain measured at 300GHz, the threshold of the sub-millimeter wave regime. This represents the highest frequency active circuit reported to date. These types of circuit technologies will be essential in implementing next generation imaging systems, which are more compact and have higher resolution than current systems.

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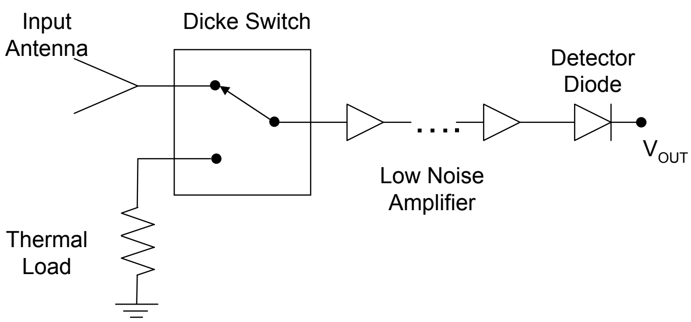

Figure 32.3.1: Block diagram of receiver architecture for FPA camera with front-end low noise amplifier and integrated Dicke switch and detector diode on a single MMIC chip.

Figure 32.3.2: PMMW images at 89GHz including (top) aerial surveillance through clouds (box at center is the MMW image superimposed on a visible image) and a concealed gun carried by a person (bottom). Black represents areas of lower received MMW power, while white represents high levels [1].

LNA	MMIC Device Technology	Device Speed	LNA frequency	LNA gain	LNA NF
[3] 7-stage	0.1µm GaAs HEMT [3]	f_T ~ 130GHz f_{max} > 250GHz	90GHz (BW ~ 10GHz)	40dB	6dB
[5] 4-stage coplanar	0.1µm InP HEMT [5]	f_T ~ 200GHz f_{max} > 400GHz	80 ~ 100GHz	20dB	3.5dB
[6]	Same as above	Same as above	151GHz	12dB	5.1dB
[8] 3-stage	70nm InP HEMT	f_T ~ 250GHz f_{max} > 400GHz	170 – 200GHz	15dB	

Figure 32.3.3: 90-to-200GHz LNA developments for PMMW imaging camera.

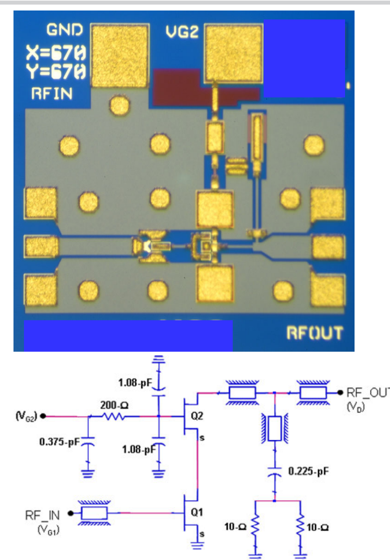

Figure 32.3.4: Micrograph and DC schematic of cascode test cell.

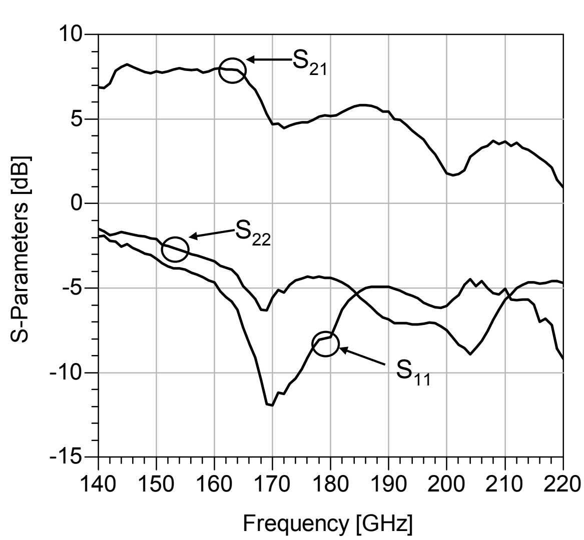

Figure 32.3.5: Measured gain and return loss of cascode amplifier.

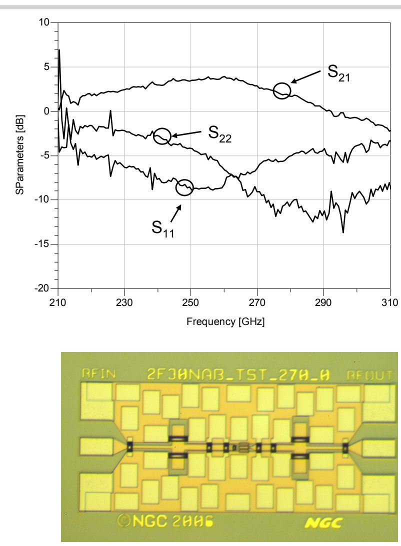

Figure 32.3.6: Measured performance of common-source (top) designed for a center frequency of 270GHz and micrograph of the amplifier (bottom).

Continued on Page 622

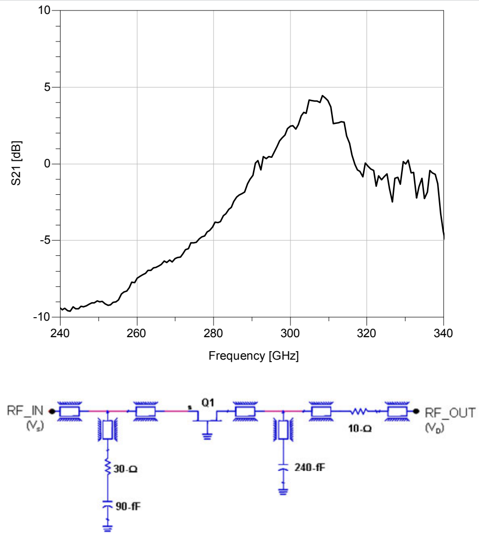

Figure 32.3.7: Measured performance of common-gate (top) designed for a center frequency of 270GHz and simplified microwave schematic of the amplifier.